VanderHaak AD: Lessons Learned

Chad Kruger, Interim Director CSANR
Craig Frear, PhD student

Northwest Dairy Digester Workshop

Sunnyside WA 11/18/08

CLIMATE FRIENDLY FARMING™

People

The dairy anaerobic digestion research work completed at WSU is a result of a generous grant by the *Paul Allen Family Foundation* to the Climate Friendly Farming project. Involved researchers and participants include:

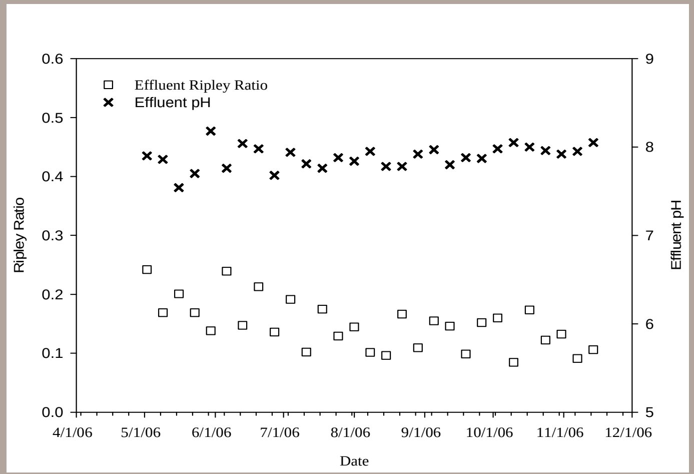
- *Management:*
  - Chris Feise, David Granatstein, Chad Kruger
- *Producers:*
  - Darrell and Steve Vanderhaak
- *Providers:*
  - Andgar Corporation; Marlin Statema, Bryan Van Loo, Kyle Juergens, Brad Weg
- *Professors:*
  - Shulin Chen, Claudio Stöckle, Joe Harrison, Craig MacConnell, Richard Shumway, Hal Collins
- *Researchers/Students:*
  - Tianxi Zhang, Usama Zaher, Anping Jiang, Wei Liao, Craig Frear, Göksel Demirer, Zhiyou Wen, Zhiwu Wang, Clark Bishop, Kay Oakley, Tim Ewing

Operation/Monitoring

- **Monitoring occurred at Washington's first dairy AD unit in Lynden WA which installed a GHD/Andgar mesophilic plug-flow digester with axial mixing;**
- **Co-digestion occurred at ~18.7% volumetric flow using different substrates including: egg breakage, fish breading, ravioli sauce, and artificial crab**

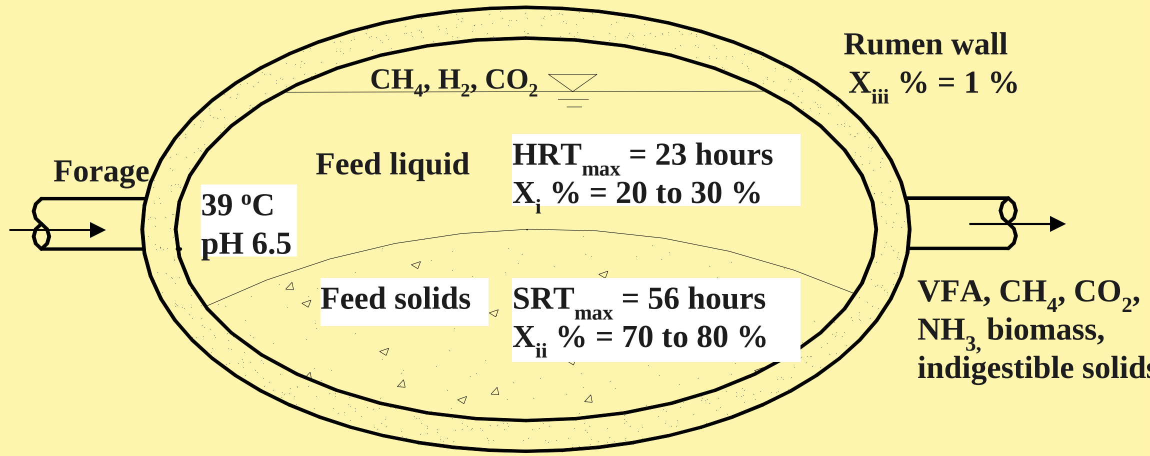
Parameter	Unit	Mean [a]
Cows	AU	938 ± 87
Effective Volume	m^3	3,899
Manure Flow	m^3/day	96.58 ± 31.13
Substrate Flow	m^3/day	18.69 ± 0.87
Total Flow	m^3/day	114.33 ± 30.93
Percentage Substrate	%	17.83 ± 5.69
HRT	days	32.1 ± 6.17
OLR	kg VS/m^3 day	1.85 ± 0.48
Temperature	ºC	37.8 ± 0.5
Design	GHD Modified Plug Flow with Axial Mixing	
Manure Handling System	Scrape Pit/AD/Screw Press/Storage Lagoon	
Engine Set	Caterpillar G398 coupled to a 450 KW Generator	

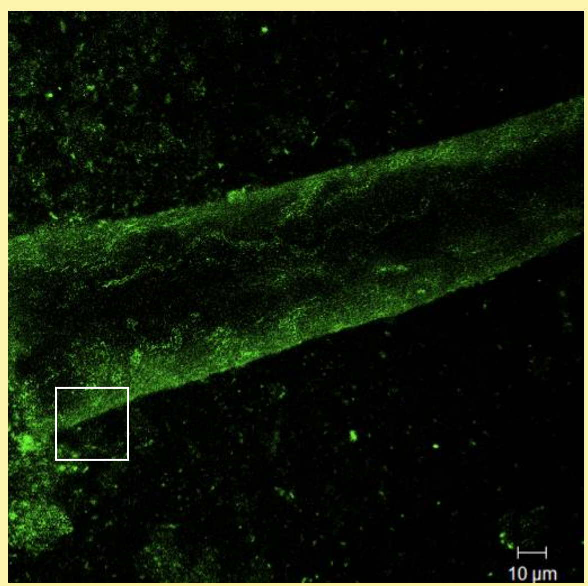
- **Despite non-optimal loading of substrates into the digester, the digester showed good stability which improved slightly over time as the digester became more acclimated to stresses induced—as indicated by consistent effluent pH and Ripley Ratio**

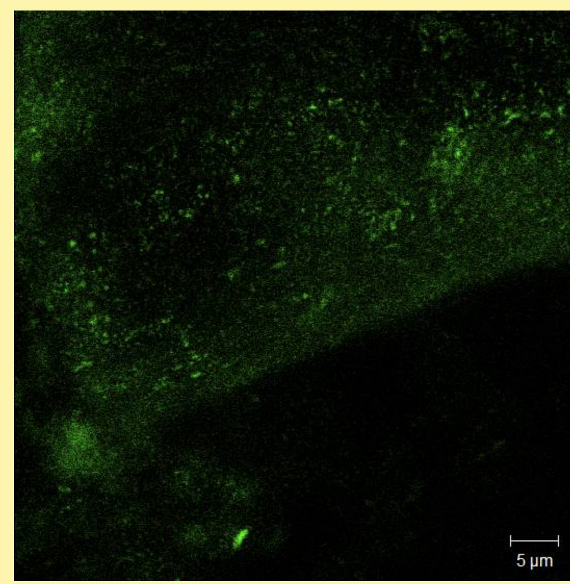


Bacteria

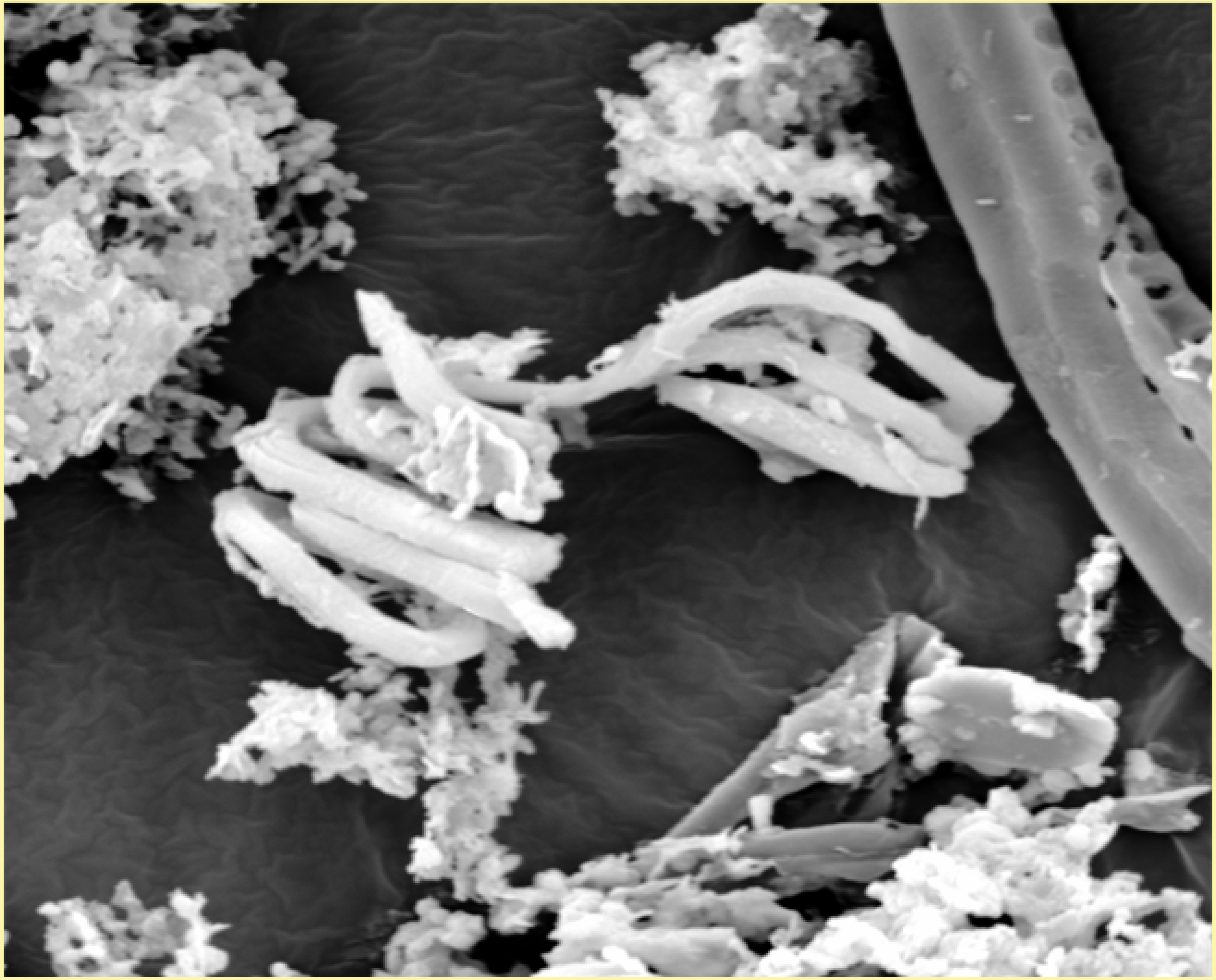
- Bacterial biomass concentrated on the fibrous particles within the manure







Bacteria



Vector Reduction

- **The digester is quite effective in accomplishing important vector reductions;**
- **Lack of statistically-relevant differences in influent/effluent TKN, TP and FS show that minimal to no accumulation is occurring in the digester; confirming the modified mixing protocol as successful;**
- **Pathogen reductions as studied through indicator fecal coliform analysis shows 99% or 2 $\log_{10}$ reductions in the effluent of the digester**

Parameter (g/L)	Influent	Effluent	Mean % Reduction
TS	70.42 ± 12.13	41.82 ± 4.03	40.61
VS	59.51 ± 7.49	30.52 ± 3.50	48.71
FS	12.54 ± 1.69	11.35 ± 1.93	NA
COD	84.13 ± 15.04	36.58 ± 5.74	56.62
VFA	7.71 ± 1.76	0.05 ± 0.02	99.35
TKN	4.12 ± 0.93	3.84 ± 0.53	NA
TAN	1.87 ± 0.45	2.65 ± 0.76	+41.71
TP	0.51 ± 0.14	0.44 ± 0.10	NA
K	2.31 ± 0.35	2.28 ± 0.27	NA
pH	6.87 ± 0.41	7.88 ± 0.14	+14.37
Alkalinity	8.96 ± 1.00	14.23 ± 1.80	+58.82
FC (cfu/g)	339,031 ± 247,461	3,418 ± 7,060	98.99

NA refers to mean reduction parameters not statistically relevant as determined by
General Linear Model (GLM) ANOVA analysis with Statistical Analysis System program 9.0 (SAS Institute Inc. NC)
at $\alpha = 0.05$ with n=24 samples. All reductions were with calculated p-values <0.0001 except for FS (0.2531), TKN (0.2355), TP (0.0417), and K (0.4567).

Gas/Electrical Production

- Biogas Production was well above previously reported EPA (2005) report on similar digester (~109 ft^3/cow day). Reporting values per cow is problematic;
- Substrate addition did lead to an increase in mean CH_4 percentage; H_2S values were elevated and were tied to particular sulfur/protein-rich substrates added.

Parameter	Units	Co-Digestion
Total Biogas	ft^3 biogas/day	155,031 ± 18,046
Total Biogas	ft^3 biogas/ cow* day	232.4 ± 27.1
Specific Methane Yield	ft^3 CH_4/kg VS $_{Added}$	15.6 ± 1.8
Specific Methane Yield	m^3 CH_4/kg COD $_{Added}$	10.2 ± 1.2
Specific Methane Yield	L CH_4 /kg COD $_{Destroyed}$	512.9 ± 59.7
Reactor Performance	m^3 biogas/ m^3 reactor day	1.13 ± 0.13
Biogas Composition	%CH_4; %/H_2S	63.52 ± 6.89; 0.20 ± 0.12

- Biogas to electricity with a rebuilt Caterpillar G398 engine coupled to a generator with a capacity of 450kW per hour. Engine efficiency is approximately 30% in converting the Btu’s in the gas into electricity.
- Improvement in engine efficiencies from other manufacturers which range from 37% - 39% efficient. This increase in efficiency results in an increase of electricity produced per a given amount of biogas.

Economics

- **Federal grants do have an important economic effect on projects and play a vital role;**
- **Trucking manure to digester is negatively offset by fuel and operation costs;**
- **Low electrical sale prices, as in PNW, negatively affect the economics with even 1 cent increases important;**
- **Co-digestion is extremely important, especially given low electricity sales;**
- **Other incomes such as carbon trading and value-added fiber sales can play an important role.**

Scenario	NPV $	NPV % Change from Base	IRR %	IRR % Change from Base
Base Scenario	1,372,777		18.68	
Alternative Digester Life, Investment, and Operational Scenarios				
10 Years	553,901	-59.65	14.80	-20.77
30 Years	1,660,989	20.99	18.93	1.35
Increase by 1%	1,186,654	-13.56	18.68	0.00
No Grants	946,099	-31.08	10.18	-45.48
Increase by 250 Cows	1,016,246	-25.97	15.35	-17.85
Decrease by 250 Cows	1,497,113	9.06	20.04	7.28
1,300 Cows, No Food Waste	1,721,941	25.43	23.42	25.40
Electricity Generation Scenarios				
No Power Generation	153,685	-88.80	4.50	-75.91
Increase by $0.01/kwh	1,692,841	23.32	21.63	15.82
U.S. average $0.0877/kwh	2,579,420	87.90	29.38	57.30
327 kwh Output	1,990,036	44.96	22.44	20.14
Tipping Fee Scenarios				
No Tipping Fees	-1,994,344	-245.28	-	-
Decrease Tipping Fees by 50%	-142,032	-110.35	-0.89	-104.77
Carbon Credit Scenarios				
No Carbon Trading	1,108,807	-19.23	16.30	-12.72
25% Commission	1,519,023	10.65	20.19	8.11
ECX Prices	2,513,094	83.07	28.86	54.52
Fiber Scenarios				
No Fiber Sales	1,262,199	-8.06	17.63	-5.63
All Fiber, $13.50/ton	1,966,705	43.26	22.17	18.67
All Fiber, $20.00/ton	2,462,566	79.39	25.34	35.68

Economics

	Co-digestion		Manure-Only	
Gross Receipts	$/AU yr	$/yr	$/AU yr	$/yr
Tipping Fees	195.61	183,484		
Electrical Sales	141.57	132,792	75.83	71,128
Carbon Credit	19.68	18,464	19.68	18,464
Avoided Bedding Cost	15.25	14,300	15.25	14,300
Tax Credit	56.63	53,117	30.33	28,451
Fiber Sales	10.94	10,265	10.94	10,265
Other Income	4.59	4,306	4.59	4,306
Total Revenue	444.27	416,727	156.62	146,913
Operating Costs				
Delivery	50.68	47,539	50.68	47,539
Maintenance	78.43	73,571	78.43	73,571
Utilities	32.13	30,139	32.13	30,139
Miscellaneous	31.15	29,226	31.15	29,226
Ownership	81.09	76,063	81.09	76,063
Total Operating Costs	273.49	256,538	273.49	256,538
Return to Risk	170.78	160,189	-116.87	-109,625

- **Co-Digestion with its *tipping fees* and subsequent *extra biogas production* and corresponding *electrical sales and carbon credits* show a very large effect on overall digester economics;**
- **Extra receipts from co-digestion can represent as much as *64%* of the total digester revenue;**

*****Conclusions based on ~18% volumetric flow of substrate composed of protein and lipid-rich industrial food processing waste and a modeled estimate of manure-only outputs***

Co-Digestion Concerns

Concerns do arise with co-digestion

•Co-digestion can bring considerable amounts of nutrients and/or salts to the farm-gate with USDA APHIS (2004) reporting that 36% and 55% of US CAFO dairies already experience N and P overloads on their farm land, respectively.

Nutrient	Manure-Only metric tons/yr	Co-Digestion metric tons/yr	% Change %
Ammonia N	89.7	110.66	23.37
Total N	102.31	160.36	56.74
Total P	16.29	18.37	12.77
Total K	101.89	95.2	-6.57

•In addition, concerns regarding management of solid waste, permitting and air/water/pathogen protection have brought regulatory debate to the practice.

Substrate	EU	Ontario
Manure	No Pre-treatment	No Pre-treatment
Field Green Waste	No Pre-treatment	No Pre-treatment
Pre-Consumer Food Processing (No ABP)	No Pre-treatment	No Pre-treatment
Pre-Consumer Food Processing (ABP)	70C for 1 hour	70C for 1 hour
Post-Consumer Food Waste	70C for 1 hour	NO
Slaughterhouse Solids of > than 6 mm	133C, 3 bar for 20 min	70C for 1 hour
Slaughterhouse water	No Pretreatment	70C for 1 hour
Mortalities and Certain Tissues	NO	NO

Producer/Supplier Lessons

- **The digester itself is a simple operating system that if kept satisfied with proper temperature and feedstock will operate very well with little disruption *(high alkalinity, simple engineering and mixing design).***
- **Most of the operator’s time is spent on the supporting equipment such as pumps, separators, and the engine.**
- **Proper operation and preventative maintenance will improve the operating efficiency of the supporting equipment.**
- **The digester’s co-products are slowly being recognized as a larger part of the value of owning a digester.**
- **Many of the unique environmental benefits of AD fail to be recognized by environmental regulation groups (odor, pathogen reduction, fertilizer).**
- **There are a lot of digester systems and accessories that are unproven and require due diligence before reaching commercialization.**

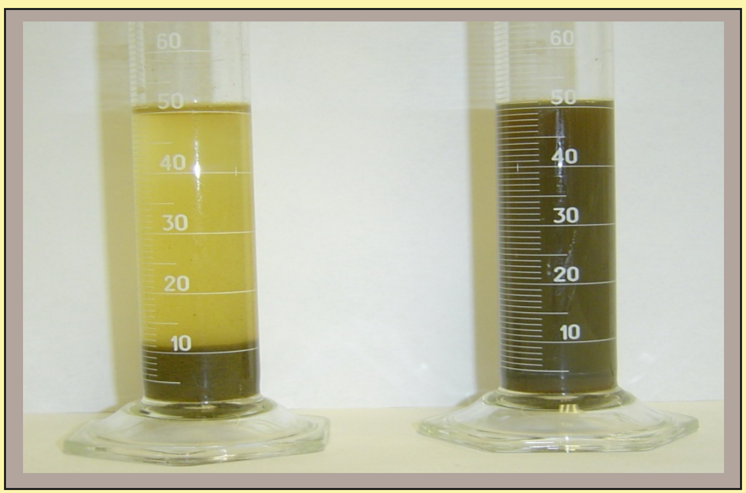
Nutrient Recovery-P

Recovery of P-Solids from AD effluent

•P in the AD dairy manure is NOT readily available with as much as 50% of TP tied up as calcium or magnesium micro-crystalline salts < 74 microns;

•Course fiber separation results in only ~20% removal of TP from the AD effluent;

•Struvite crystallization of AD dairy manure yields only 15% TP removal as compared to 90% when utilizing swine. This can improve to >70% if chemicals such as EDTA are introduced.



•Polymers appear to be well suited for flocculating the suspended P, such as PEI with MW near 1 million. Low dosage can result in 70% TP removal.

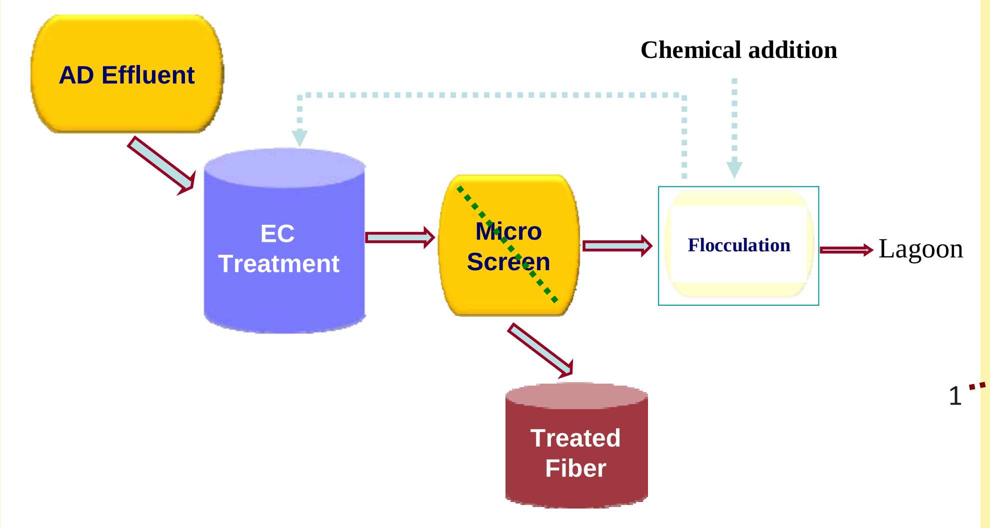
Nutrient Recovery-P

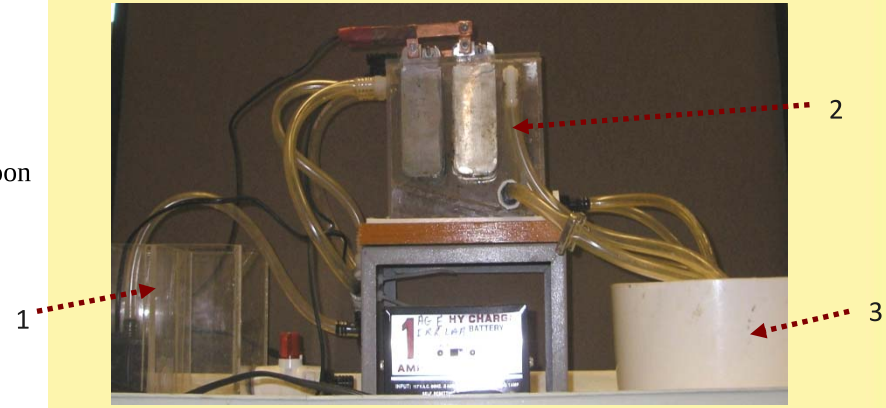
Recovery of P-Solids from AD effluent

•Electro-coagulation experiments confirm that ~ 5 minutes residence time in apparatus allowed for ~70% TSS and ~52% TP removal, respectively;

•System needs more testing and optimization;

•Testing multiple systems to optimize TP removal while also reducing capital and operation costs

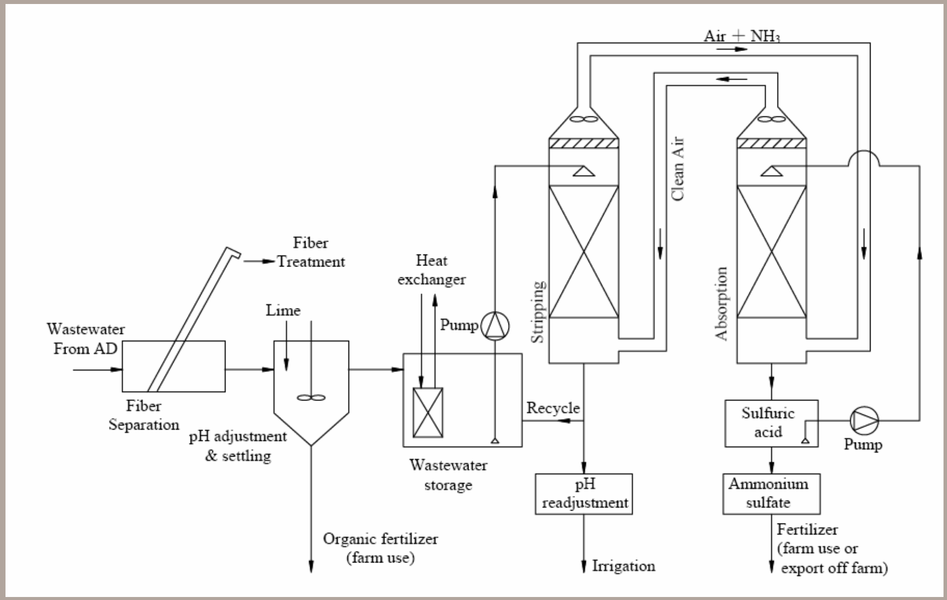




Nutrient Recovery-N

Recovery of Ammonia from AD effluent

•Ammonia stripping recovers ammonia sulfate slurry with high enough concentration to warrant export and sale off of the farm;
•Operation is optimized to dairy conditions, i.e. 30-35C, pH=10, lower air cycle rate, leading to roughly 75% removal and recovery of ammonia;
•Resulting de-stripped effluent is high in pH but biogas can be used to lower pH while also scrubbing it of H_2S and some CO_2

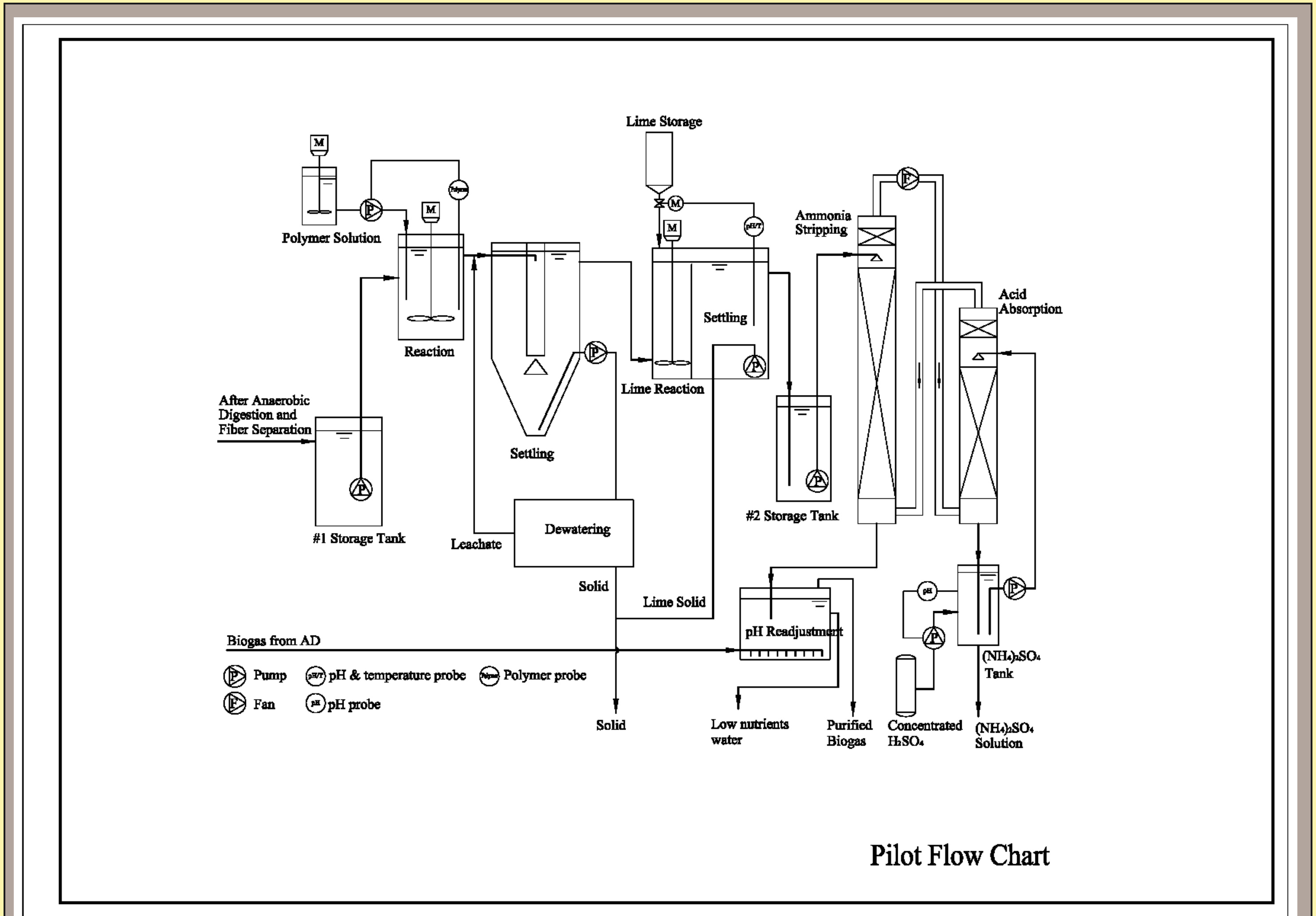


(a) pH adjustment and settling system

(b) Ammonia stripping and absorption system

Nutrient Recovery-ALL

Pilot-testing at ~2 gpm on-going at Vanderhaak farm; fertilizer and economic analysis to follow



Pilot Flow Chart

High Quality Fiber

Presently

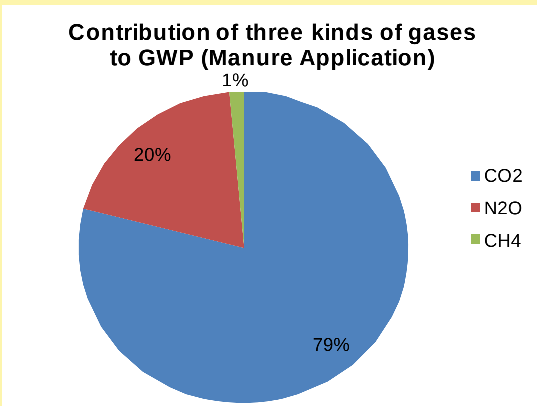
- **AD operations separate fiber after AD process and then use as … and**
-

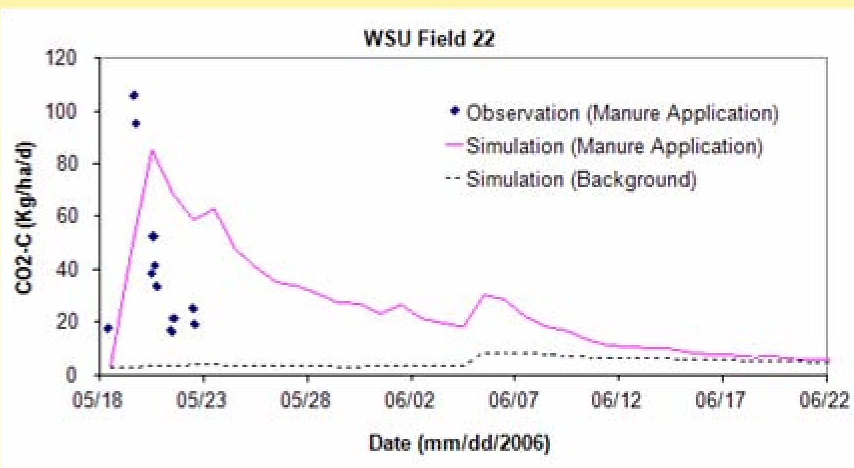
W…

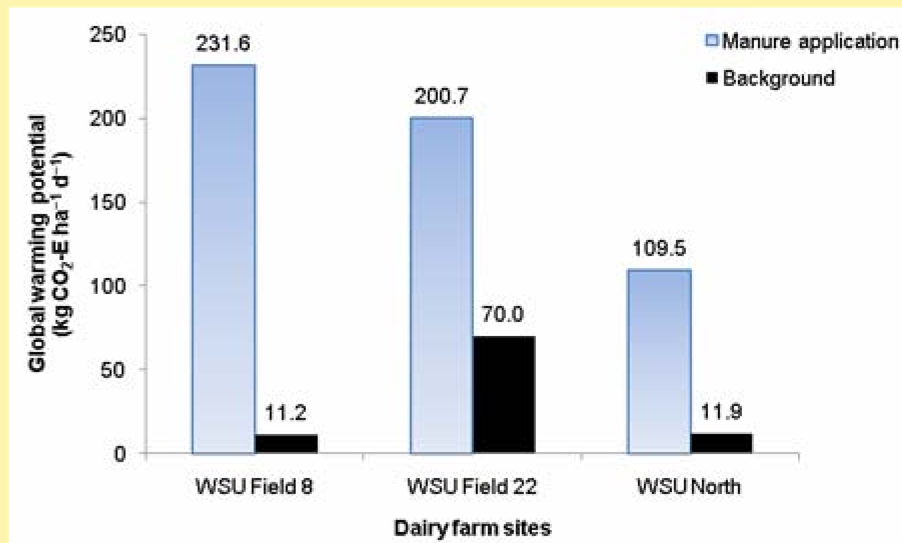
-
- **… convincing/developing market)**

Field Application

- **Analysis still on-going, however results indicating the importance of de-gasssing AD effluent of CH_4 prior to application and control of moisture, application conditions for N_2O**

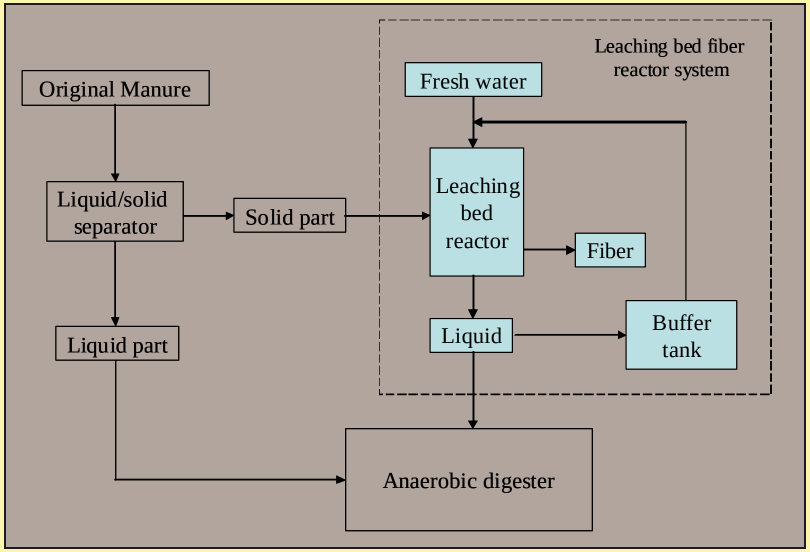


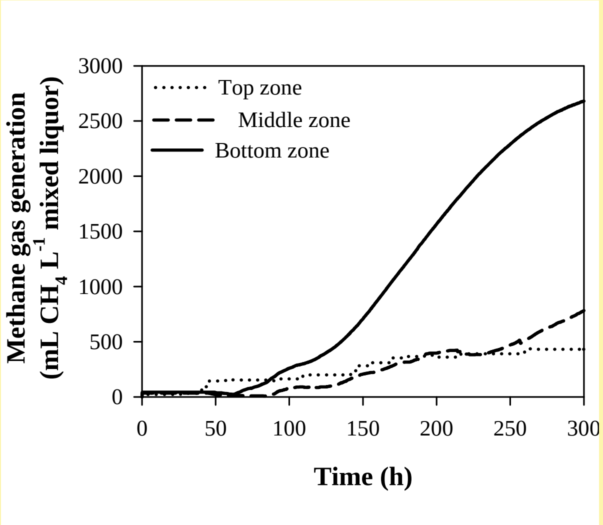


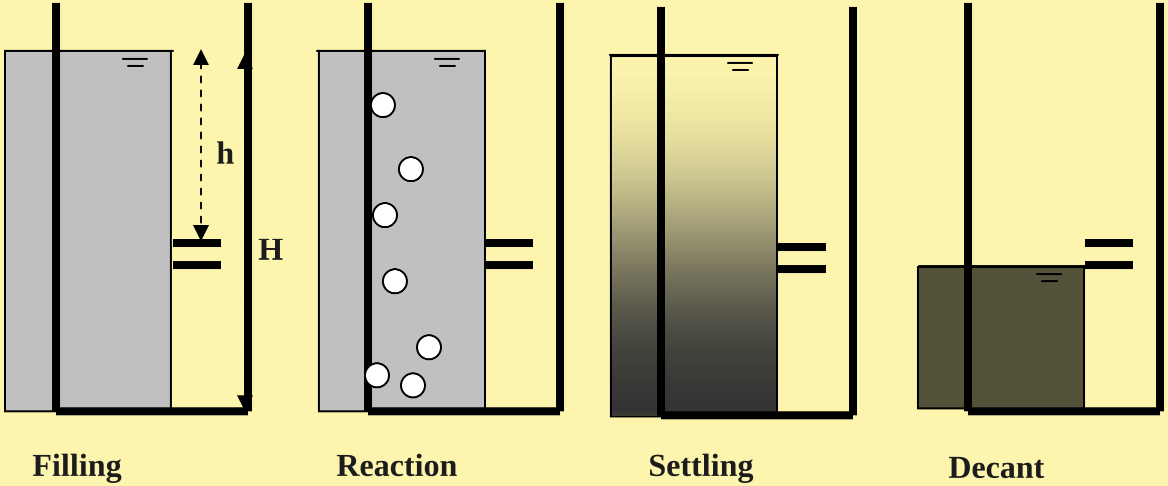


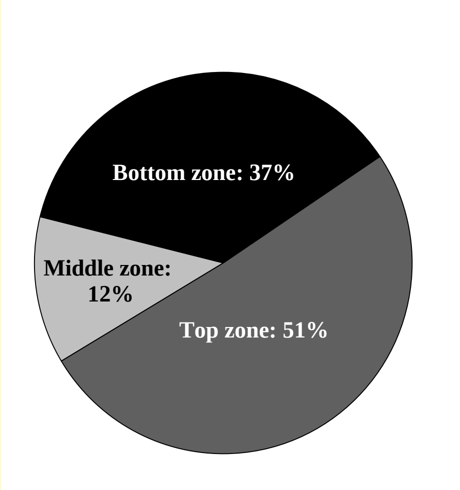
Flush System

- Analysis of flush manure and lessons learned leading to design of SBR reactor for digestion of flush dairy manure









Funding

Department of Ecology

THE PAUL G. ALLEN FAMILY foundation

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